THE QUESTIONABLE STRATEGY OF SOIL-ONLY LANDFILL COVERS

A large scale field study of percolation through six different landfill final cover cross sections at Sandia National Laboratories in Albuquerque, New Mexico. The primary focus of the Sandia field study was to evaluate three soil-only strategies: namely, capillary, anisotropic and thick soil cross sections. As a secondary focus they also were compared to three traditional cross sections; the first contained a geomembrane and compacted clay, the second contained geomembrane and geosynthetic clay liner (GCL) and the third consisted of a low-permeability compacted soil. However, the two sections that included geomembranes had holes deliberately punched in the geomembranes (and perhaps the GCL as well) during installation. In contrast, none of the soil materials at any of the test plots were comparably damaged during construction. The negative implications of this flawed field study as the performance of the geosynthetics in construction of final covers for landfills are discussed in light of the data from the Sandia Test Plots.

TR 239
7/03

The Questionable Strategy of Soil-Only Landfill Covers

A White Paper from the Geosynthetic Research Institute

Synopsis

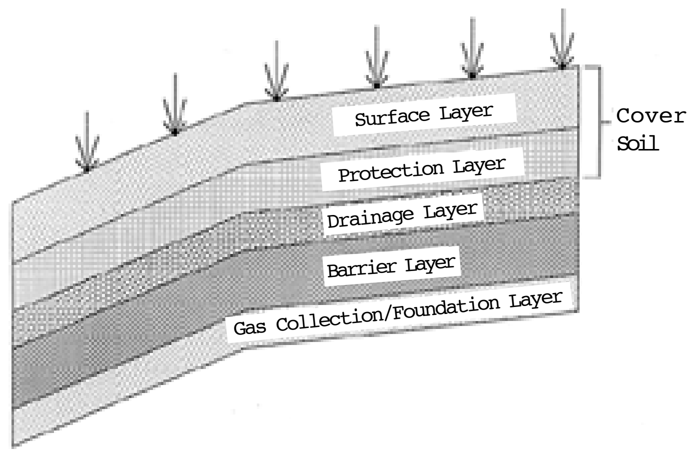
A large scale field study of percolation through six different landfill final cover cross sections at Sandia National Laboratories in Albuquerque, N.M., has prompted this white paper. The primary focus of the Sandia field study was to evaluate three soil-only strategies; namely, capillary, anisotropic and thick soil cross sections. As a secondary focus, they were also compared to three traditional cross sections; two contained geomembranes and the third consisted of a low-permeable compacted soil. However, the two sections, which included geomembranes, had holes deliberately punched in the geomembranes (and perhaps the geosynthetic clay liner as well) during installation. In contrast, none of the other materials at any of the test plots were comparably damaged during construction. The negative implications of this "flawed" field study as to the performance of geosynthetics in construction of final covers for landfills are discussed in light of the data from the Sandia Test Plots.

Background

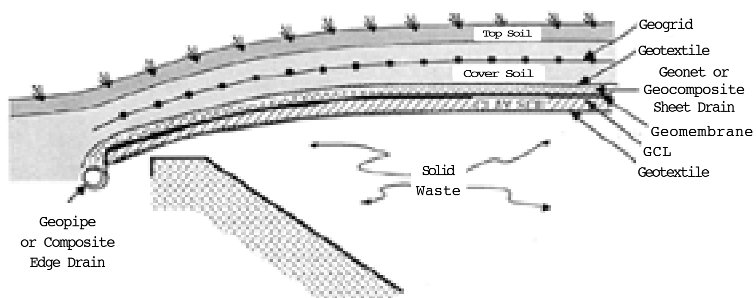
The final cover of a closed landfill containing either hazardous or nonhazardous waste is a challenge to a designer due to a number of inherent variables; for example,
(i) type and extent of the waste mass,
(ii) hydrologic conditions at the site,
(iii) condition and/or existence of the base liner system,
(iv) sensitivity of the surrounding environment,
(v) connectedness of the landfill to ecological pathways,
(vi) design lifetime of the proposed final cover, and
(vii) potential future beneficial use of the site.

As a result, landfill final covers are always site-specific designs. Yet, there are some generalities related to the design of the specific layers that a designer must consider. **Figure 1(a)** presents the identification of the general layers, and **Figure 1(b)** presents the geosynthetic materials that are often used to replace or augment some, or all, of the natural soil materials that might be used. To be sure, geosynthetics can and have played a critical and very positive role in providing environmentally safe and secure final covers at hundreds (perhaps even thousands) of closed landfill facilities. See, for example, the data base accumulated by Othman, Bonaparte and Gross (1997).

Figures 1a and 1b. Cross sections of final covers for landfills, after Koerner and Daniel (1997).



(a) Essential layers of a natural soils' final cover system.



(b) Geosynthetic alternative for final cover system.

It is readily acknowledged, however, that such final covers of either type are not inexpensive as the generalized cost estimate in **Table 1** indicates.

In assessing the specific items in the above table, it is seen that the physical construction item represents approximately half of the total cost. As such, construction

Table 1. Estimated costs of engineered landfill final covers (Koerner 2001).*

Item	Description	Cost/Acre	Cost/Hectare
exploration	sounding/test pits	15,000	31,000
design	plans/specifications/permits	25,000	62,000
construction	earthwork/geosynthetics	70,000	172,000
inspection	MQA/CQA	10,000	25,000
guarantee	insurance/bonding	20,000	50,000
maintenance	vegetation/fencing/signage	10,000	25,000
	TOTAL	$150,000	$365,000

*These are approximate costs; they are extremely site specific and can vary by as much as 50% from site-to-site.

(including materials) is logically a major target insofar as possible cost reduction is concerned. Depending on the number and types of geosynthetics (recall **Figure 1b**) and the size and location of the project, one could target the geosynthetics as being a candidate for removal from the cross section (environmental safety and security issues aside) so as to decrease the overall cost of the final cover. It appears as though this is the approach that is being taken under the title of "alternative landfill covers," a.k.a. inexpensive soil liners without geosynthetics. There appear to be two different approaches to soil-only covers; capillary (or anisotropic) barriers and thick monolayer barriers. Each will be briefly described.

Capillary (anisotropic) barriers

A fairly recent development is the use of a layer of fine-grained soil overlying a layer of coarse-grained soil to form a capillary barrier. Typically, this is sand overlying gravel where the differences in hydraulic conductivity (or permeability) are 3 or 4 orders of magnitude. A slight variation is called an anisotropic barrier. The idea of both capillary and anisotropic barriers is as follows: Soil moisture in the subsurface reaches equilibrium when the soil water potential is the same throughout. If a layer of fine- and coarse-grain soil are in equilibrium and there is no movement of water between the layers, the two layers will have the same soil water potential. For a given soil water potential, a coarse-grained soil will tend to have a much lower water content, i.e., be much drier, than the overlying fine-grained soil. Furthermore, the permeability of unsaturated soil decreases exponentially with decreasing water content because flow paths through thin films of water coating the soil particles in a relatively dry soil are extremely tortuous. A dry gravel is actually much less permeable to small quantities of water than a moist sand.

Thus, if the subsoil remains unsaturated, a fine-grained soil overlying a coarse-grained soil will tend to function with the uppermost soil layer retaining nearly all of the soil moisture and the underlying layer serving as a de facto barrier to water percolation due to its dryness. These two distinct soil layers are called a capillary barrier system. Note, however, that in a capillary barrier, lateral movement of water in the fine-grained soil occurs in the unsaturated state. For this reason the upper soil layer is sometimes referred to as a wicking layer.

There are a number of concerns with capillary barriers. One is that the fine-grained soil must not be allowed to migrate downward over time into the underlying coarse-grained soil. Obviously, this would completely destroy the concept and system's functionability. A geotextile, used as a separator, should be considered for placement beneath the fine-grained soil and above the coarse-grained soil. For extremely long service lifetimes, the durability of the geotextile must be assessed for this application. Alternatively, a graded granular soil filter might be used instead of a geotextile, but this tends to mitigate the differences in permeability upon which the concept is based. A second concern is over sloping portions of the system where the wicked water in the fine-grained soil can accumulate and eventually break through into the coarse-grained soil. The third concern is over periods of high (relatively speaking) concentrated precipitation or snow-melt. In such cases, the capillary barrier concept may cease to function, at least temporarily, as the coarse-grained soil becomes moist and loses its water impeding capability. Clearly, these concerns are in need of investigation using large scale or full scale test plots as is being done in the study to be described.

Irrespective of the concerns that were just mentioned, it is generally agreed that capillary barriers can only be considered for arid or semi-arid areas where precipitation is low and does not occur in short term increments, i.e., the precipitation is relatively evenly spaced throughout the year. Also, note that the terms arid and semi-arid are quantified indexes. Thornthwaite (1948) uses a moisture index defined as annual precipitation minus evapotranspiration in units of inches per year. In doing so, an arid climate is between -60 and -40. A semi-arid climate is between -40 and -20. This definition restricts the applicability of capillary barriers in the United States to the southwest for arid areas, and other western areas (except for the Pacific coast) for semi-arid areas.

Thick monolayer barriers

Monolayer barriers are covers that include a thick layer of fine-grained soil generally covered with a layer of vegetated topsoil. They are also called evapotranspiration covers. This type of thick cover encourages water storage and enhances evapotranspiration year-round, rather than just

Table 2. Materials used to construct the Sandia Cover Test Plots.

Number	Characterization	Layers (Top-to-Bottom)
1	Subtitle D Barrier (Soil)	Topsoil (150 MM); Compacted Soil (450 mm)
2	Subtitle C Barrier (with GM/CCL)	Topsoil (600 mm); Geotextile; Sand (300 mm); Geomembrane (with Holes); Compacted Clay (600 mm)
3	Subtitle D Barrier (with GM/GCL)	Topsoil (600 mm); Geotextile; Sand (300 mm); Geomembrane (with Holes); Geosynthetic Clay Liner
4	Capillary Barrier	Topsoil (300 mm); Sand (150 mm); Gravel (220 mm); Barrier Soil (450 mm); Sand (300 mm)
5	Anisotropic Barrier	Topsoil (150 mm); Soil (600 mm); Fine Sand (150 mm); Gravel (150 mm)
6	Thick Monolayer Barrier (Evapotranspiration)	Topsoil (150 mm); Soil (900 mm)

during the growing seasons. The soil allows water storage, which, when combined with the vegetation, will increase evapotranspiration. Monolayer barriers exploit two characteristics of fine-grained soils: (i) their large soil moisture storage capacity when unsaturated, and (ii) their low saturated permeability relative to coarse-grained soils (Morrison-Knudsen 1993). The soil's low saturated permeability limits infiltration through the surface during rainfall or snowmelt. The soil's high moisture storage capacity makes it capable of storing water that does infiltrate until it can later be removed by evapotranspiration. The barrier must be sufficiently thick, however, such that changes in water content do not occur near its base; i.e., all changes in soil moisture storage must occur in the upper portion of the soil barrier. Otherwise, water will percolate into the underlying waste. The necessary thickness is a function of the amount of precipitation received, the unsaturated hydraulic properties of the soil, and the rate at which water can be removed by evapotranspiration. Monolayer barriers are constructed from silty sands, silts, and clayey silts. These soil barriers can be cost effective when large quantities of fine-grained soil requiring little processing are available on site.

Geologic Associates (1993) describes a field study conducted to assess the performance of a thick soil barrier used as final cover for a landfill in Southern California. The barrier was 2-m (6.6-ft)-thick and was constructed from a clayey silt. Water movement was limited to the upper 0.6 m of soil; no changes in water content were observed at the base of the barrier. The data indicated that the water content of the upper soil layers increased rapidly after rainfall and then decreased as water was removed by evapotranspiration. However, the data collection time was only a few years and subsequent data is not available to our knowledge.

Concerns over thick monolayer soil barriers focus on preferential flow pathways which can develop in monolayer barriers as a result of (i) desiccation cracking, (ii) root growth and penetration, and (iii) burrowing animals. Sufficient data about the performance of monolayer barriers have not been gathered from which to judge their reliability and effectiveness in this regard, Benson and Khire (1995). They feel that field tests, including large-scale measurements of percolation, are needed before definitive conclusions regarding monolayer barriers can be drawn.

The Sandia Test Plots

In an attempt to evaluate both alternative and traditional (geosynthetic-related) final landfill covers, the U. S. Department of Energy funded a field study at Sandia National Laboratories (Kirkland Air Force Base) in Albuquerque, N.M. (see Dwyer, 1998 and 2001). While clearly stated in the available reports that the study "… is not intended to showcase any particular cover system," the bias included in the field deployment of the geosynthetics did precisely that. The results in the traditional (geosynthetic-related) test plots did not perform as well as would be expected and in one case did not perform as well as the soil-only test plots. The text to follow presents the details of the Sandia Test Plots.

The test plots of Sandia are each 13 m wide by 100 m long. Half of each length faces east (which includes sprinkler systems) and the other half faces west (which includes passive monitoring). All slopes are at 5%. **Table 2** presents the essential details of the six test plots.

Test Plots 1, 2 and 3 are considered to be traditional, in that the barrier layers are 450 mm of compacted clay, a composite liner consisting of a geomembrane over 600 mm of compacted clay, and another composite liner consisting of a geomembrane over a geosynthetic clay liner, respectively. Since they follow U.S. EPA guidance, these test plots are called Subtitle D (Soil), Subtitle C (GM/CCL) and Subtitle C (GM/GCL). Of overriding importance is the fact that the geomembranes in Test Plots 2 and 3 were purposely damaged by the incorporation of eight 1 cm^2 defects (puncture holes) punched through them during construction. If, and how far, the steel rods making the punctures penetrated the underlying GCL and/or CCL is not known. Paradoxically, the drainage system for data collection beneath all six of the test plots consists of geonet drainage composites and geomembrane liners with no holes punched in them! As far as the soil-only test plots, Test Plots 4 and 5 are both variations of a capillary barrier system (called capillary and anisotropic, respectively) and Test Plot 6 is a thick soil monolayer.

As mentioned previously, each of the six test plots were underlain by a underdrain system consisting of a geonet composite and a geomembrane. The collected percolation water from the geonet composite was routed to a collection system and measured accordingly.

Table 3. Measured percolation rates in units of mm/year through the Sandia Landfill Cover Test Plots (Dwyer 2001).

Year	Precipitation Volumes Collected (L)	Plot #1 Subtitle D (Soil)	Plot #2 Subtitle C (GM/CCL)	Plot #3 Subtitle C (GM/GCL)	Plot #4 Capillary Barrier	Plot #5 Anisotropic Barrier	Plot #6 Thick Monolayer
1997 (May 1-Dec. 31)	154,585	10.62	0.12	1.51	1.62	0.15	0.22
1998	169,048	4.96	0.30	0.38	0.82	0.14	0.44
1999	130,400	3.12	0.04	4.31	0.85	0.28	0.01
2000 (Jan. 1–June 25)	28,151	0.00	0.00	0.00	0.00	0.00	0.00
Average		4.82	0.13	1.81	0.87	0.16	0.19

To our knowledge, there were no intentional defects placed in any of the soil material test plots, i.e., Test Plots 4, 5 or 6. For example, there were no soil nonhomogenities, preferential flow paths, different compactive energies, different placement moisture contents, etc., purposely induced into the soil materials. Thus, one can expect at the outset that Test Plots 2 and 3 (with geomembrane holes) will be overestimated insofar as their percolation (leakage) is concerned and thus behave relatively poorly in light of what would be expected with proper construction. Also Test Plot 1 with its relatively high permeability is expected to behave poorly. It might be noted that many regulatory agencies and designers discount this particular cross section completely. Thus, before one even looks at the test results, the outcome is essentially known, i.e., that the alternative landfill covers will be favored with much lower leakage than the Subtitle D (soil) section and possibly the Subtitle C sections (with holes in the geomembranes) as well.

The Sandia test results are presented in Table 3 for the three-year time period from May 1997 through June 2000. According to Dwyer (2001), the first year was apparently quite wet, while the second two years were extremely dry.

Commentary by Dwyer (2001) on these test results is as follows:

Test Plot 1 – "by far the worst design"

Test Plot 2 – no comment

Test Plot 3 – "appears to be degenerating with time"

Test Plot 4 – no comment

Test Plot 5 – no comment

Test Plot 6 – "appears to be leading the way"

Dwyer (2001) goes on to say about Test Plot 6, "This test reveals that in dry environments a well-designed simple soil cover is not only the cheapest alternative but also the most effective at controlling infiltration." Thus, even before the anticipated five-year results are recorded, the conclusion is finalized, as could have been anticipated on the basis of the original experimental design and its flawed construction insofar as holes in the geosynthetics are concerned.

Summary

The "flawed" large scale field study funded by the U. S. Department of Energy at Sandia National Laboratories in Albuquerque, N.M., has clearly driven the need for this GRI white paper. Had the study focused on soil-only landfill covers and investigated the nuances of capillary, anisotropic and thick monolayer barriers by themselves, it could have been a valuable contribution to the body of knowledge in this particular application. Unfortunately, the comparison to traditional soil covers with purposely flawed geomembranes (and perhaps GCLs and CCLs as well) serves absolutely no purpose. Geomembranes need not have holes, and with proper construction quality control (CQC) superimposed with proper construction quality assurance (CQA), holes have been often completely eliminated. Obviously, holes can occur. However, if flawed construction practices are the target of the investigation, all other materials should have deficiencies purposely installed in them as well. This includes such well known soil inconsistencies as nonhomogeous materials, differences in placement moisture contact and compactive energy, differences in varying soil layer thicknesses and uniformity, etc. As far as Test Plot 1 with its relatively thin soil layer of high permeability (in the range of 10^{-3} to 10^{-5} cm/s), it appears in the test program as a "red herring." Most knowledgeable people (regulators and designers) know this is an inadequate final cover concept and simply ignore its existence.

In summary, geomembrane or geosynthetic clay liners create environmentally safe, secure final covers for landfills, especially when they are used in tandem as a composite barrier. As shown in the U. S. EPA study, (Othman, Bonaparte and Gross, 1977) geosynthetics clearly work!

Thus, the results of the Sandia Test Plot study are of interest insofar as the soil-only cross sections are concerned, but are completely irrelevant with respect to those incorporating geosynthetics. In this regard, it is disappointing that a federal agency should sponsor and conduct such a comparative study, particularly when it appears to be contrary to the recommended U.S. EPA and most state EPA regulations for final covers of closed landfill facilities.